Traffic Literature Review: Congestion and Quality of Intersections

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compiled for the Hamline Midway Coalition Transportation Committee

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Executive Summary:

Due to the heavy use of the University corridor and Snelling Avenue, their junction is a key intersection for St Paul. The resulting traffic congestion can be both a burden and a benefit to the Hamline Midway neighborhood. This was brought to the attention of the media in 2006, when the city of St Paul published the Snelling/University Capacity Study, proposing that the level of traffic congestion is high enough, and the level of service of the intersection low enough that action should be taken to increase the transportation capacity there.

This study provokes several questions. First, how can an "acceptable" level of congestion be determined and measured? Also, how can the quality of an intersection be determined? What criteria did the city use, and what alternate criteria exist?

These questions can be explored using literature that addresses the two main transportation issues of the neighborhood: traffic congestion and heavily-used intersections. This review addresses traffic congestion first, with literature that determines its effects – both positive and negative –on neighborhoods, residents, and business, as well as methods to measure and rate these effects. Second, the review address intersections by listing the factors that affect users' intersection experiences, and the ways these factors can be used to make a measurement of intersection quality. Last, some of the literature reviewed is briefly applied to the St Paul area.

This paper provides a context for transportation issues and their connections to the Hamline Midway neighborhood. Background knowledge of congestion and intersections is not only necessary for understanding and responding to city transportation action, but for discovering and pursuing one's own transportation goals.

Transport: An Overview

What are the objectives of transport? Who are the actors involved?

The issue of transport is addressed by groups that range in professional status from federal administrative bodies to independent non-profit organizations, without a set list of priorities or objectives between them. The government uses platitudes, pledging to pursue "safe and efficient transport" but providing no measures to evaluate it (Levinson, 2005); engineers measure service to maximize flow at highest speed and to identify and correct congestion; planners use service standards to measure the "quality" of systems, efficiency of vehicle flow, and "ideal" balances of business/housing. The primary influences in the field of transport today include the policies of the state and federal government, engineering guidelines created by the Transportation Research Council, and trends in the field of planning.

Approach of Government to Transport Issues

The DOT system:

The US government addresses transport issues through the federal and state departments of transportation (DOTs). The federal DOT has oversight on interstate transportation, whereas state DOTs oversee regional transport and the maintenance of their state highway systems. The US Department of Transportation (DOT) system's mission is to "serve the United States by ensuring a fast, safe, efficient, accessible and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future" (US DOT website). The federal and state DOTs work to achieve this by planning, funding, and building the transportation systems of the US, as well as creating the laws and regulations that address transport. Many traffic and highway issues are dealt with through the Federal Highway Association (FHWA), a division of the US DOT.

The Highway Capacity Manual:

The federal guidelines for how to build transportation facilities and rate their performance are compiled in The Highway Capacity Manual (HCM), a publication put out by the Transportation Research Board, a nationally-funded independent research group, with support from the DOTs.

Since the first edition of HCM in 1950, "it has been viewed as the authoritative reference document for use in conducting engineering analyses aimed at determining the operational adequacy of a transportation facility"(TRB, 2004). The 1950 edition, at 147 pages, was used primarily by civil engineers, for sizing and designing highway facilities. The 2000 (the fourth and most recent) edition contains around 1,100 pages describing basic travel characteristics (speed, volume, and passengers carried, etc.), mode of travel (private vehicle, walking, biking and transit), level of analysis (planning, design and operation), influence area (point, segment, facility, corridor and system), type of analysis ("look-up" table, analytical, or computer simulation), and condition (under-saturated or oversaturated). In sum, it presents methods of analyzing capacity and quality of service for most types of transportation (TRB, 2004).

The Texas Transportation Institute

Another major actor in the field of transportation is the Texas Transportation Institute, a member of the Texas A & M University system. The TTI has conducted the Urban Mobility Report, a status update on the congestion in major cities, since 1982. Sponsored by a consortium of state departments of transportation and several interest groups, the report tracks congestion patterns in the 75 largest US metropolitan areas. The main mission of the UMR is to convert traffic counts to speeds, so that delay can be computed. Since 2002, the UMR has also reported on the contributions operational strategies and public transportation have made to reduce delay (Bertini, 2005). Although technically published privately, this resource is used and supported uniformly by the federal government, state DOTs, urban planners, and civil engineers.

Alternative Approaches to Transport

The most common criticism of the US government's system of transportation management is a perceived auto-centrism. In speech given to a national conference on traffic congestion, president of the Surface Transportation Policy Project Ann Canby argues that state departments of transportation shy away from land use issues, pursuing highway investments that feed congestion. For example, an average of only 6.5 percent of federal transportation dollars between 1992 and 1999 were devoted to alternatives to roads. In addition, federal money for new public transit systems usually provides a 50% match, as opposed to the 80 % match typical for highway projects. Gas funds also tend to be restricted to road-building rather than all transportation uses. According to Canby, this focus on cars and highways is a result of pressure from politicians and developers for auto-oriented land development, which in turn increases the demand for roadways (Canby, 2003).

This trend towards sprawl, increased highway systems, and thus more car traffic has been countered by alternative movements that stress transit, high-density planning, and mixed land use.

Transit-Oriented Development:

According to the overview of Transit Oriented Development used by the St Paul Central Corridor Taskforce, TOD is a "pattern of land development designed to support public transit services." TOD uses strategies of land use and economic development to promote other types of transportation than cars, in ways such as planning pedestrian-friendly downtown areas and interspersing businesses with residences. This notion is related to Transportation Demand Management, the strategy of addressing traffic problems by discouraging the use of cars and encouraging other modes of transport. The purpose of both of these strategies is "to reduce the use of single occupant vehicles by increasing the accessibility and number of trips by walking, bicycle, car/van-pool, bus, street car, ferry or rail" (St Paul PED, 2006).

The Center for Transit Oriented Development (CTOD) is the authority on the approach, acting as a federally-funded clearing house for the best practices and standards for Transit Oriented Development. It describes TOD as including practices such as: developing within a half mile of transit stops, linking transit networks to those of biking and walking, mixing land-use (residential and business), development that caters to pedestrians, highly connected street networks, appropriate amounts of parking, appropriate levels of density, and high quality design (Center for Transit Oriented Development website).

The approach focuses on the district, not the site, in order to promote district connectivity, to create a better transport network, and to allow sites to specify their functions.

The goals of projects created with Transit Oriented Development are to:

1. Increase "location efficiency" so people can walk and bike and take transit
2. Boost transit ridership and minimize traffic
3. Provide a rich mix of housing, shopping and transportation choices
4. Generate revenue for the public and private sectors, providing value for both new and existing residents
5. Create a sense of place

With these objectives in mind, the CTOD hopes to achieve "attractive, walkable, sustainable communities that allow residents to have housing and transportation choices and to live convenient, affordable, pleasant lives – with places for our kids to play and for our parents to grow old comfortably" (CTOD website).

Accessibility:

Another approach to transportation, a focus on accessibility over mobility, stems from recent academic research done in the field of transportation studies. This approach criticizes transportation planning and policy for focusing too much on congestion mitigation and too little on metropolitan accessibility. According to a transportation expert from the University of Michigan, mobility – or the ability to move quickly and freely - is important, but accessibility – the ability to reach the goods and services – is the final objective of transportation (Levine, 2003). Distance doesn't necessarily correlate with accessibility, so some locations become more proximal with respect to travel times, creating a "warp" of space, whereas some do not (Janelle, 1969).

Mobility improvements reduce the costs of transportation per mile, since commuters move farther more quickly, whereas accessibility improvements reduce the costs of transportation per destination, since the focus is placed on reaching the destination. Traffic policy focuses on congestion mitigation, which improves mobility but not necessarily access. Transportation experts who emphasize accessibility believe that transportation is a 'derived demand' of access, a means and not an end to itself, and thus policy should change its focus towards increasing access.

Congestion:

The Federal Highway Administration (FHWA) defines traffic congestion as "the level at which transportation system performance is no longer acceptable due to traffic interference" and that "the level of system performance may vary by type of transportation facility, geographic location (metropolitan area or sub-area, rural area), and/or time of day" (Lomax, Turner and Schunk, 1997). Specific cases, such as freeway congestion in the state of Minnesota, is defined more precisely as traffic flowing below 45 miles per hour for any length of time in any direction, between 6am and 9am or 2pm and 7pm on weekdays. However, since other types of roadway congestion depend upon the area, the facility and "acceptability" (the subjective notions of ideal speed and mobility), the methods of measuring and tolerating congestion vary.

Costs and Benefits of Congestion

Typically seen as a burden for travelers and those in the immediate vicinity, arguments have been made both for and against congestion by those in the field of transportation.

Costs:

Traffic congestion is most often criticized as a waste of time and money, a cause of pollution and stress, and a detriment to productivity (Bertini, 2005), imposing costs on society equal to 2 to 3 % of the gross domestic product (Cervero, 1998). For 2002, it was estimated that congestion "wasted" $63.2 billion in 75 metropolitan areas because of extra time lost and fuel consumed, a sum equal to $829 per person (Schrank and Lomax, 2004).

The FHWA suggests reducing congestion for the following reasons:

1. Reducing total congestion saves time and fuel and decreases emissions.
2. Reducing congestion at border crossings lowers transportation costs, benefits the national economy, and fosters international trade.
3. Reducing the amount of time travelers spend on the road reduces their exposure to unsafe conditions like traffic incidents, driving in poor weather, and driving in work zones.
4. Congestion impedes the efficacy of service providers (such as fire and emergency response vehicles).
5. Congestion 'steals' time from personal travelers who could be doing productive work.
6. Congestion causes foregone investment opportunities: higher transportation costs from congestion reduce a firm's ability to invest in making more products, improving quality, and introducing new products.
7. Congestion causes decreases in regional employment or decreases in the rate of growth of regional income: higher transportation costs are passed into other economic sectors.

Benefits:

In response to negative attitudes towards congestion and increased roadways, some traffic analysts have stressed the benefits of congestion. Brian Taylor, an urban and regional planning researcher, challenges both criticism of congestion and criticism of autocentric transportation policy through the following propositions (Taylor, 2002):

1. Traffic congestion is a sign of social and economic vitality.
2. Expanding the capacity of road systems may lead to recongestion (see "Induced Demand", p 10), but this does not mean the expansion is a 'failure': congestion may not have been eliminated, but the expansion increased capacity and fostered social and economic activity.
3. Other forms of congestion management, such as improved bus routes and ramp metering are also vulnerable to the effects of induced demand.
4. Changes to current land-use arrangements would take decades to reshape development patterns and thus travel behavior. The link between compact urban development and walking trips is unclear and complex.
5. High-density development decreases car usage, but partly by increasing congestion.
6. Until motorists pay the full cost they impose on society, development patterns that favor cars offer the best chance to reduce congestion

7. The high levels of access to a variety of economic and social transactions in metro areas increase congestion, an often overlooked aspect of accessibility (Taylor, 2003).

His view is a direct response to trends like Transit Oriented Development, accessibility-focused transport studies, and high-density development, which antagonize congestion and road-building, focusing on changing land-use and increasing density to mitigate congestion.

Taylor is not alone in his tolerance of congestion. Downs (2004) and Taylor (2002) assert that if "successful cities are places where economic transactions are promoted and social interactions occur", then traffic congestion occurs where "lots of people pursue these ends simultaneously in limited space". Cervero (1998) also notes that congestion is not necessarily negative, since it can be a sign that "a community has a healthy growing economy and has refrained from over-investing in roads". Garrison and Ward (2000) add that unpopular places rarely experience congestion.

Beyond tolerating congestion, some even tout its benefits as an end within itself. Several studies show travelers report enjoying their commutes as periods of privacy, reflection and relaxation between home and office (Mokhtarian, 2005; Ory and Mokhtarian, 2005; Handy, et al., 2005).

How does Congestion affect Business?

The presence of congestion is a paradox for business: if congestion worsens, it might drive businesses and economic activity to less congested locations, however congestion-solving methods (such as pricing the entry of automobiles into central business districts or enacting stringent parking limits and fees) could also push businesses away. Thus political strategies tend more to accommodate congestion than to regulate it (Wachs, 2003). However, it remains important to examine at what level businesses enjoy the visibility that congestion brings in, and at what level the costs of congestion override the benefits.

In 1995, a study was conducted by Cambridge Systematics and published by the National Cooperative Highway Research Program (NCHRP) that examined the effects of congestion on businesses and efforts to mitigate them. This study established that the costs and benefits of congestion depend upon the type of business affected.

Four main costs of congestion were determined: the discouragement of clients because of increased travel time to obtain goods and services; the cost of employees' increased commute (more funds needed for recruitment and retention combined with less productivity); the increased cost of delivering goods and services; and the increased cost of receiving goods and services (through disruptions to operations, the need for more inventory as buffer for delays, and the cost of congestion added to the cost of goods).

The study additionally examined how these costs affected different types of businesses.

1. It was determined that **urban retailers** may locate themselves in congested areas for the benefits (such as increased access to their business and exposure), and they also suffer less of the congestion costs. Generally, the retailers are open for business after the morning rush hours, so the commute costs are negligible. Customer traffic for urban retailers also tends to be highest during midday off-peak hours and is primarily walk-in traffic, mitigating the cost of client travel

time. Also, the small volume of their stock allows retailers to schedule shipping and receiving for midday or the night to avoid congestion.

2. **Walk-in business and customer service operations**, which include banks, health-care facilities, and hotels, suffer a moderate degree of congestion costs. Employees work staggered shifts, so some of them suffer commute costs; however, customers then have the flexibility to schedule trips around traffic congestion. Goods movement is limited to high-value, low-bulk shipments usually handled by courier services or dedicated shuttles. Parking is the greatest cost, as it tends to be high-priced and scarce.
3. **Field service and repair operations**, which include home and office equipment repair businesses, office supply businesses, sales units, construction businesses, and professional services (i.e. engineering and property appraisal) send their employees to travel repeatedly during business hours, so their exposure to congestion is great. However, "wherever possible, these businesses tailor their operations to minimize travel distance and time" (TRB, 1995). In downtown areas, clients are grouped in small service areas that can be covered on foot, and in suburban areas, parts and equipment are stocked at dispersed locations so that service personnel don't need to travel to a central office or warehouse. The density of clients in downtown areas makes the productivity and profitability of these services higher in congested areas than other areas.
4. **Office, administrative, research and development, back-office and headquarters operations** are only lightly exposed to the costs of congestion. They suffer the cost of increased employee commute, but the businesses generally have few people or goods moving during the day, so congestion places few other costs on business.
5. **Manufacturing businesses** are moderately exposed to congestion. Staggered shifts lower employee commute costs, and the ability of large manufacturers to operate 12 to 24 hours a day means that they can conduct night shipping and receiving. Trends toward "just-in-time operations" have increased their exposure to congestion; however, this trend is often offset through relocation to suburban and exurban areas.
6. **Warehousing, distribution and trucking operations** are among the businesses most exposed to traffic congestion costs. These businesses conduct most of their travel in the morning after businesses open and in the afternoon right before businesses close. Operations are tightly planned to minimize travel time and delay, and in highly congested areas the density of customers creates economies of scale that make it profitable to operate even in congested conditions.

Businesses mitigate the costs of congestion through the following measures: additional vehicles and staff, off-peak or night travel, telecommunications, and satellite bases and branches.

Business managers tend to ignore congestion costs because (TRB, 1995):

1. The type of business travel most exposed to congestion is employee commuting; since society views employee commuting costs as the responsibility of the employee, most businesses don't it as a direct cost.
2. Transportation costs are a relatively small proportion of the total cost of providing most goods and services.

3. Often, compensating economies of scale and operational expertise gained by working in densely developed and, therefore, congested areas allow the business to operate efficiently and profitably.
4. Costs of commuting are shifted to the public sector – business managers tend to view transit as the "escape valve" for worsening traffic congestion.
5. Congestion is not perceived as a competitive factor since the cost of congestion is a pervasive phenomenon, a constant presence that affects all businesses operating and competing in the metropolitan area.
6. Businesses adjust their operations to minimize the cost of congestion.

The phenomenon of Induced Demand:

What is induced demand?

When roadway systems are increased by either opening new roads or widening existing ones, the observed increase in traffic that occurs soon afterwards is called "induced demand" (FHWA website). The term is most often used by advocacy groups (such as those involved in TOD or Transportation Demand Management) who argue that "we can't build our way out of traffic congestion", since increased capacity just encourages more driving. The phenomenon of Induced Demand is occasionally called "recongestion", and is related to the concept of "latent demand": the additional peak-period vehicle trips that will occur if congestion is relieved on a roadway (Litman, 2007).

To what degree does it occur?

To determine the existence of induced demand, the Surface Transportation Policy Project examined the 23 metro areas with the largest growth in road capacity (the average number of lane miles of roadway per person grew by an average of 17 percent), and the 23 with the least capacity between 1990 and 1999 (the road space per person declined almost 14 percent). In that time period, both groups had nearly identical rush hour congestion levels and they experienced the same increase in both the Travel Rate Index and Annual Hours of Delay. The population growth was not a confounding factor, and, in fact, the average population growth for the low road-building group was actually mildly greater. Also both groups (high-road-building and low-road-building) had a similar number of very large, large, medium and small cities and population sizes overall.

The STPP's analysis shows that adding more space on the road system does not slow growth in congestion, despite a higher rate of road building than population growth in metro areas studied. Also proven was that in the last decade, one-third of metro areas surveyed that had added the most road space per person experienced a 6.5 increase in rush hour congestion, compared to a 7.2 percent increase in the metro areas that added the least road capacity. Low-road-building areas had higher population growth, eliminating that as an explanation for the demand differences. Travel delay was actually higher on average in the 23 metro areas that built the most roads (STPP, 2001).

Why does it occur?

Latent and induced demand occur due to a variety of reasons. Pickrell (2003) described how when speed on the expanded facility initially rises (due to capacity improvements), in the short-term travel is diverted to it from other parallel facilities or routes, from trips previously made at other times of day, and from other modes. Effects of induced demand extend to the long-term, where one notices more household trips, less household trip-chaining, and more frequent business-generated orders and shipments.

Some induced demand comes from economic growth in a region and land development attracted to the newly available capacity (Cervero 2003; Noland and Lem, 2002). This leads many researchers to believe that despite the fact that increasing capacity may not solve congestion (due to induced demand), it does encourage economic growth and increases the amount of people who can access a specific destination.

Different Methods of Addressing Congestion:

Congestion is not always seen as a problem that needs solving, but when it is, the approaches to the issue tend to fall in three broad categories:

Supply Management

Supply Management includes all measures taken to increase the number of people and trips served by the transportation system in order to accommodate as much demand as possible. This includes added capacity for cars as well as transit, bicycle, pedestrian, and multi-mode facilities (Meyer, 2003).

Adding capacity through this method is made controversial by the induced demand argument and the environmental and health effects of additional travel and land consumption. Furthermore, critics argue that the majority of traffic jams are caused by accidents and events – not lack of capacity (STPP, 2001). Perhaps as much as half of urban congestion arises from so-called "non-recurring" incidents, such as vehicle crashes and breakdowns (Gifford, 2005). Supply Management methods do little to mitigate congestion caused by non-recurring incidents.

Land Use Management

Land-Use Management describes the use of growth management, planning, and zoning to promote local density to encourage transit. Transit Oriented Development and high-density land use are both examples of this type of management.

Critics of Land Use Management site the increased congestion created by high-density development, the long length of time it would take to change land-use patterns and behaviors, and doubt regarding the connection and causality of the two (Taylor, 2002).

Transportation Demand Management

Transportation Demand Management (TDM) is a strategy of instituting largely financial incentives and disincentives to encourage motorists to alternate routes, times and modes, or to defer trips entirely in order to reduce the demand for traffic facilities. TDM arises out of a desire to consider alternatives to "supply-side" measures because of the negative community effects of induced demand. Measures include:

a. **Congestion pricing**: using tolls and fees to induce travelers to change the time they travel, mode they use or passengers they bring along
b. **Park-and-ride lots**: available parking close to transit or carpool facilities promoting alternate modes of transportation than single-occupant vehicles
c. **High-Occupancy-Vehicle lanes**: lanes reserved for vehicles with two or more travelers, referred to commonly as carpool lanes or "diamond" lanes
d. **High-Occupancy-Toll lanes**: lanes that allow access for a price to single occupant vehicles
e. **Employer Commute Option programs**. Using on-site or dedicated transportation coordinators to encourage ridesharing and other TDM measures

f. **Telecommuting**: the ability to work from home, eliminating a work commute altogether
g. **Alternative work schedules**: work schedules that promote commutes during non-peak periods
h. **"Cashing out"**: the ability for employees to exchange their access to free parking for subsidized transit
i. **Traffic Calming Measures**: reducing speed of traffic by narrowing lanes and adding speed bumps

Of all the measures, pricing tends to be both the most effective and politically legitimate as a funding source, an important concern as it has become clear that the HTF is insufficient for paying the nation's transportation needs and Congress needs new revenues (Gifford, 2005). However, due to the cost it places on drivers, congestion pricing is one of the hardest methods to implement.

Measuring Congestion

Measurements and Definitions used by US Government:

The UMR (Urban Mobility Report), although conducted privately by the Texas Transportation Institute, is sponsored by a consortium of state departments of transportation (as well as several interest groups) and is used uniformly by government and private organizations as a standard for measuring congestion.

It uses several measured variables reported as part of the Highway Performance Monitoring System (HPMS). HPMS was developed by the FHWA and the states in 1978 to promote a systematic, national approach for identifying highway conditions, estimating capital investment needs, and measuring changes in highway conditions over time (Hill et al. 2000). A collection of 70 data elements that states are required to report, the HPMS includes information on pavement condition, traffic counts, and physical design characteristics of some 100,000 highway segments.

The UMR uses this data to report seven primary performance measures:

1. **Annual Delay per Traveler**: extra travel time for peak period travel during the year for freeways and principal arterials, measured in hours per person per year
2. **Travel Time Index**: a ratio of travel time in the peak period to the travel time at free flow (ideal) conditions and the amount of people that experience each index of congestion
3. **Travel Delay**: extra travel time for peak period travel above that required for travel at free flow conditions
4. **Excess Fuel Consumed**: increased fuel consumption due to congestion
5. **Congestion Cost**: value of delay and excess fuel consumption converted to dollars per person
6. **Buffer Time Index:** travel time reliability indicating how much of a time buffer one needs to arrive within the average travel time for a given trip
7. **Roadway Congestion Index**: a general measure of the degree of overall congestion

The FHWA uses these seven performance measures in their Mobility Monitoring Program in which they are trying to answer a mobility question ("how easy is it to move around?") and a reliability question ("how much does the ease of movement vary?").

Off all the measures listed, congestion is most commonly measured in delay (in hours), intensity (average percent time delay during peak periods compared to ideal conditions), extent (percent of peak-period travel that is congested), and reliability (variation of the other three elements) (Lomax, Turner and Shunk, 1997).

Criticisms to conventional measures of congestion:

Many argue that the measures of congestion ignore the effects of congestion on individuals and firms, and should be customer-oriented and reflect what the community wants from the transportation system. Measures such as average delay or average travel time ignore other important measures, such as travel time reliability, which focuses more on the individual than the trip, making it more meaningful. Measuring the effects of congestion for the individual consumer can extend to other congestion-related issues; for example, air quality can be measured by individual human inhalation. (Meyers, 2003; Taylor, 2003)

Alternative Measures of Congestion:

The methods used to measure congestion are constantly being reviewed and adjusted by the government and independent organizations. For example, a 2003 synthesis by NCHRP examined more than 70 possible performance measures for monitoring highway segments and systems. From users' perspectives, key measures for reporting the quantity of travel included: person-kilometers traveled, truck-kilometers traveled, vehicle kilometers traveled, persons moved, trucks moved and vehicles moved. In terms of the quality of travel, key measures included: average speed weighted by person-kilometers traveled, average door-to-door travel time, travel time predictability, travel time reliability (percent of trips that arrive in acceptable time), average delay (total, recurring and incident-based) and LOS. (Bertini, 2005)

The Surface Transportation Policy Project has been exploring alternate measures of congestion as well. It takes into account an area's level of congestion and the degree to which people use non-automobile transport to avoid it. These are calculated through the "**Congestion Burden Index**": the TTI's 1999 travel rate index multiplied by the percentage of the workforce driving to work from the 1990 US Census. A high rank on the index indicates that congestion places a higher burden on residents because congestion is worse and fewer of them are escaping it. Cities that rank high for rush-hour congestion such as Washington DC (4^{th}) and San Francisco (2^{nd}), don't necessarily rank high for Congestion Burden, where they are 31^{st} and 29^{th} respectively, due to high usages of alternate forms of transport. Conversely, Detroit ranks 15^{th} on the Travel Rate Index but 3^{rd} in the Congestion Burden Index due to the high percentage of drivers.

The STPP measured the relative availability of transportation choices in metro regions through the "**Transportation Choice Ratio**", calculated as the miles of public transportation service per household offered over the period of one hour divided by the number of lane miles of principle arterials per household in that area. Comparing the TCR with the percent of workers vulnerable to congestion with a simple bivariate correlation reveals a relatively strong relationship (R^2=.73). This implies that there is a strong reason to believe that a large amount of transit compared to roadways is related to having fewer workers vulnerable to congestion. (STPP, 2001)

Intersections

Official Measures of Intersection Service

The Highway Capacity Manual details an array of operations to measure the performance of signalized intersections. All of these operations are based upon three types of input parameters: Geometric, Traffic, and Signal. Geometric conditions include the number of lanes, lane width, percent gradation, parking, etc. Traffic conditions include peak-hour factor, number of local buses stopping at intersection, approach speed, percent heavy vehicles, flow rate, etc. Signalized conditions include cycle length, green time, pedestrian push-button, actuated versus pre-timed operation, etc. Once these conditions are measured, performance is measured in delay, progression adjustment, level of service, capacity and back of queue[1] (HCM, 2000). The two most commonly used measures of intersection performance are capacity and level of service.

Capacity

Capacity is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. "A principal objective of capacity analysis is to estimate the maximum number of persons or vehicles that a facility can accommodate with reasonable safety during a specified time period. However, facilities generally operate poorly at or near capacity; they are rarely planned to operate in this range. Accordingly, capacity analysis also estimates the maximum amount of traffic that a facility can accommodate while maintaining its prescribed level of operation" (HCM, 2000: 2-1).

Level of Service:

LOS for signalized intersections is defined in terms of average control delay per vehicle measured in seconds per vehicle. Control delay is the portion of the total delay attributed to traffic signal operation for signalized intersections. This includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay: basically all of the time between slowing down for an intersection and passing through it (HCM, 2000: 16-1).

Signalized intersections are assigned grades of Level of Service A through Level of Service F, depending on their degree of control delay. Level A includes control delays below 10 seconds; level B, 10 to 20 seconds; level C, 20 to 35 seconds; level D, 35 to 55 seconds; level E, 55 to 80 seconds; and level F, over 80 seconds.

According to the HCM 2000, design or planning efforts typically use service flow rates at LOS C or D "to ensure an acceptable operating service for facility users" (HCM, 2000: 2-3)

Meaning of LOS:

The Highway Capacity Manual 1997 defines level of service as "a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers." Specifically, the levels are meant to measure driver discomfort, frustration, fuel consumption and lost travel time, established "on the basis of

[1] Back of queue: length of the line of cars waiting at an intersection

the acceptability of various amounts of delay to drivers" (HCM, 1997: 2-3). Thus, the amount of control delay is used as a marker for drivers' perceptions and acceptance of intersection performance.

Criticisms of LOS:

Pecheux and Pietrucha criticize the HCM's use of control delay as a marker for driver perceptions in their 2000 study. The study notes a variety of issues with the measurement of Level of Service including:

1. The HCM level of service for signalized intersections is not based on studies of driver perceptions of delay, but field-observed actual delays from 336 intersection approaches.
2. The HCM only specifies control delay as a factor that influences user perception of service quality.
3. The threshold separating "acceptable" from "unacceptable" conditions is a value of 60 seconds per vehicle, which was chosen as the maximum value "tolerated" in a survey of traffic engineers - not motorists, passengers, or pedestrians.
4. The HCM uses the same delay thresholds that were established 15 years ago·

In response to these criticisms, Cameron (1996) and Baumgaertner (1996) proposed extending the LOS criteria from A to J and A to I, respectively. Cameron stated that high levels of congestion and delays were becoming more and more common, and Baumgartner noted the growth of population, vehicle ownership, trip length and number of trips have resulted in increased traffic volumes. Thus, today's commuters have become accustomed to heavier traffic than commuters of the 1960s were.

The preliminary results of Pecheux's study suggested that subjects did not perceive LOS on six levels, but in three or four levels of service, at least regarding delays of around 100 seconds or less. Subjects were more tolerant of delays than the HCM guidelines would suggest, and their LOS ratings tended to be similar for delays associated with LOS A and B, and LOS C and D. Thus, future studies should perhaps concentrate on users' perceptions of longer delays, suggests Pecheux (2000).

Pecheux's post-experiment discussions "revealed that about 90 percent of the subjects considered delay to some extent; however, very few subjects used delay as the only criterion when rating LOS" (Pecheux, 2000: 332-333). Group discussions showed at least 15 factors that influenced LOS ratings: Delay, traffic signal efficiency, arrows and lanes for turning vehicles, visibility of traffic signals from queue, clear/legible signs and road markings, geometric design of intersection, leading left-turn phasing scheme, visual clutter/distractions, size of intersection, pavement quality, queue length, traffic mix, location, scenery/aesthetics, and presence of pedestrians (Pecheux, 2000).

Intersection Service for Pedestrians

Intersection Characteristics that Affect Pedestrians:

The FHWA's Signalized Intersection Guide provides context and explanations for the important factors that affect pedestrians at signalized intersections. Generally, the factors that they outline – Delay, Vehicle Conflict, and Vehicle Speed – are used to measure whether specific intersections are pedestrian-friendly.

1. Delay

A general rule of thumb indicates that pedestrians at crossings are willing to wait only 30 seconds; afterwards, they start to look for opportunities to cross, regardless of the walk sign and the crossing location (HCM, 2000: 18). Lights with shorter cycle lengths benefit pedestrians, especially when they need to cross the street in both directions (to get to a diagonal corner), as well as drivers, who experience generally shorter delays (FHWA, 2004).

2. Vehicle Conflict:

Vehicles and pedestrians at intersections tend to run into conflict in one of four situations described below (for diagram see appendix figure 9):

- *Vehicles turning right on red.* This conflict occurs most often when the driver of a vehicle turning right on red is looking to the left and does not adequately search for pedestrians approaching from the right and crossing across the path of the vehicle. In addition, the sound of vehicles turning right on red masks audible cues used by blind pedestrians to determine the beginning of the crossing phase (FHWA, 2004).
- *Vehicles turning right on green.* Vehicles should yield to pedestrians crossing the through street; when they do not, this conflict may occur.
- *Vehicles turning left on green.* When vehicles have to wait for a gap in traffic to turn left, they often do not see or yield to pedestrian traffic in the crosswalk in their path, causing this conflict.
- *Vehicles running the red light.* This conflict is the most severe due to the high vehicular speeds often involved (FHWA, 2004).

3. Vehicle Speed:

The speed of vehicles plays a major role in pedestrian safety, particularly in the case of pedestrian-vehicle collisions. For example, a pedestrian struck at 40 mph has an 85 percent chance of being killed, at 30 mph the probability of death is 45 percent, and at 20 mph it drops to 5 percent (Leaf, 1999). In addition, vehicles are unlikely to stop for pedestrians when their speed is over 45 mph; however, they are likely to stop when their speeds are less than 20mph (FdoT, 1999).

The time required for a driver to detect a pedestrian, decelerate, and come to a complete stop can be used in the design of an intersection. AASHTO's *A policy on Geometric Design of Highways and Streets* recommends a brake reaction time of 2.5 seconds for determining stopping sight distance. More research has been done that suggests that the value of 2.5 seconds represents overly-optimistic conditions (including an alert, perceptive driver), and researchers have suggested reaction times nearer to 3.2 seconds as more reasonable (Hooper and MacGee, 1983).

Measures of Intersection Quality for Pedestrians:

The factors of delay, vehicle conflict, and vehicle speed (as well as others) can be used to determine the quality of a specific intersection for pedestrians.

The HCM 2000 provides two methodologies for determining the pedestrian LOS at signalized intersections – one based upon signal delay incurred by the pedestrian, and the other based on pedestrian space requirements. Studies by Sisiopiku, Khisty, Crider, Jaskiewicz, Landis, and Chu and Baltes have all identified that factors beyond those used in the HCM influence pedestrians' impressions of how well a road facility serves their needs. The HCM acknowledges this by recommending that other factors (such as comfort, convenience, safety, security, and attractiveness) be considered; however, no guidelines are given on how to measure or use these environmental factors for designing and assessing pedestrian facilities (HCM 1985). Since the Highway Capacity Manual does not offer a measurement system that includes these factors, many unrelated researchers and organizations have created comprehensive pedestrian level of service criteria of their own. Six models of measuring pedestrian service are outlined below.

1. Khisty, C. J. "Evaluation of Pedestrian Facilities: Beyond the Level-of-Service Concept":

In 1994, this study supported the HCM's current use of a flow/speed measurement as the sole quantitative measurement of pedestrian environments. But it also identifies seven other qualitative environmental factors that can be measured by survey to augment the approach: attractiveness, comfort, convenience, safety, security, system coherence, and system continuity. The resulting theory is that a combination of the flow/speed measurement with this list of qualitative measurements should provide a good description of the quality of intersections for pedestrians (Khisty, 1994).

2. Robertson and Carter. "Pedestrian Hazard Index":

One of the earlier alternative pedestrian rankings was created in 1988 by Dr. H. Robertson and Dr. Everett Carter. Called a "Pedestrian Hazard Index", this measurement was based on hazard indicators, five of the most important being number of pedestrian accidents, pedestrian accident rate, proportion of special pedestrians crossing, non-compliance with the signal, and pedestrian/vehicle conflicts.

Each indicator was ranked between 0 and 100, with 0 being "no hazard", 33 being "low hazard", 67 being "high hazard", and 100 being "extreme hazard." For example, in a three-year period, 0 pedestrian accidents would be assigned a value of 0 (no hazard), 1 accident would be a 33 (low hazard), 3 accidents would be a 67 (high hazard), and 12 or more accidents would be a 100 (high hazard).

The accident rate would be calculated as accident frequency over exposure measure (which could be measured pedestrian volume times length of intersection). They came up with the result that pedestrian volume had a higher correlation (exponential relationship, correlation coefficient r=.321) to pedestrian accidents than vehicle volume to pedestrian accidents (linear relationship, r=.302). This implies that the pedestrian safety is more dependant on the amount of pedestrians present than the amount of cars present. Large amounts of young and elderly pedestrians were also considered a hazard, as were high percents of pedestrians in non-compliance with the signal (Robertson, 1988).

3. Pedestrian, Bicycle, Auto, Transit Level of Access (P-BAT LOA):

The Pedestrian, Bicycle, Auto, Transit Level of Access (P-BAT LOA) creates a criteria for all modes of transport that rates street segments in the middle of blocks as well as intersections. As a general guideline, the P-BAT LOA provides a list of "practical criteria" for roadway facilities for any type of transport:

- A - Facility is reasonably safe for all users 10 years or older. It may also be safe for solo users as young as 6 years old. But, in some Level A areas some children under 10 may still need to be supervised.
- B - Facility can accommodate users with basic skills and knowledge of traffic.
- C - Facility requires an intermediate level of skill and knowledge of traffic to use.
- D - Facility requires an advanced level of skill and knowledge of traffic to use.
- E - Facility is generally not suitable for pedestrians or bicyclists.

In addition to this broad rating system, the Pedestrian, Bicycle, Auto, Transit Level of Access recommends individual rating procedures for each mode of transport. Pedestrian Level of Access is rated based on four variables:

1. The width and volume of the walking area
2. The amount of a "buffer zone" between the walking area and cars
3. The volume and vehicle speed of traffic in the lane closest to pedestrians (plus three secondary factors; walk-area penetrations, heavy vehicle volumes and intersection wait-time.)

For bikes, level of access is based on three variables: outside lane width, motor vehicle speeds and traffic volume, plus three additional secondary factors: the quantity of bicycle traffic, volume of heavy vehicle traffic and outside lane penetrations.

For transit, value is placed on speed at which it can complete its route relative to the speed of alternative transportation modes. Three crucial factors in this are traffic delays, on-time operation and capacity utilization (Mozer, 2007).

4. FDoT Pedestrian LOS:

The Florida Department of Transportation uses an augmented version of the HCM pedestrian level of service that it created in conjunction with the Sprinkle Consulting Incorporation. The model is based on two broad factors: "perceived safety/comfort and operations (i.e., delay and signalization)". Their model was highly successful, and had a correlation coefficient of r squared = .73 with average observations.

The list of variables influencing pedestrians' sense of safety or comfort with the intersection included:

1. Perceived Conflicts: vehicles that cross the pedestrians' path such as right-turning motorists from the street parallel to the crosswalk, right-turn-on-red motorists from side streets, through motorists on the street parallel to the crosswalk, and left-turning motorists approaching from the street parallel to the crosswalk. This category also includes vehicles passing close to pedestrians, making them uncomfortable (through volume in the lane next to the crosswalk).
2. Perceived Exposure: crossing distance, presence of crosswalk, traffic control devices, presence of curb or sidewalk
3. Delay: cycle length for "walk" sign

The model developed for pedestrian LOS is a mathematical formula that calculates a numerical value for level of service based on: the number of right turn on red vehicles, the number of motorists per minute who make a left turn, the number of motorists per minute who pass through the intersection, the speed of traffic, the number of lanes crossed by pedestrians, and the average number of seconds of pedestrian delay (see appendix for formula).

Although the study was created specifically for and by the Florida DOT, it states that as "the participants in this study represented a broad cross section of the U.S. population of pedestrians, and the course's intersections were typical of those prevalent in the urban and suburban areas of the United States...the initial result of this research is the development of a highly reliable, statistically calibrated Pedestrian LOS model for intersections, suitable for application in the vast majority of U.S. metropolitan areas" (FDoT 1999)

5. Henson, Colin. "Levels of Service for pedestrians":

In 2000, Colin Henson published a comprehensive review of pedestrian Level of Service measurements in the influential journal *Institute of Traffic Engineers*. He reviewed the HCM pedestrian LOS guidelines and the alternative measures that have been proposed. These were synthesized into his own list of important criteria for pedestrian level of service, which are categorized by section of a pedestrian trip (walking on the street, crossing the street, and reaching a destination):

1. Walking along the street

a) Continuity: Are there any gaps or obstacles in the sidewalk or path?

b) Capacity: Is the sidewalk wide enough? (using the HCM standard)

c) Comfort: Is the walk pleasant? (using FDOT standard)

2. Crossing the street

a) Safety, comfort and convenience. (using Walking Security Index)

b) Is there sufficient queuing space? (using HCM standards)

c) Delay: Total crossing time, including how long a pedestrian has to wait for a gap in traffic or a green signal.

d) Deviation: How far does a pedestrian have to detour to reach a safe crossing point?

3. Some place to walk to

a) How well do sidewalks and crossings work as a system?

i.Travel time along a route (including crossing delay) compared to walking a hypothetical straight line route.

ii.The "ped shed" concept: How much of an area within a given radius of a destination can be reached with a 1-km walk along existing sidewalks? This can be adjusted to include delay at lights and crossings.

b) Do destinations exist? (a measure of mixed land use)

c) More involved analysis of the mix of destinations within a given walking time or distance (Henson 2000).

6. Walkability Index:

A popular method of measuring pedestrian service is through a “walkability index”, first described by Chris Bradshaw for the Ottawa area. This index lays out 10 aspects of neighborhoods (density, off-street parking places, number of sitting spots on benches, chances of meeting someone you know while walking, age at which a child is allowed to walk alone, women's perception of safety in the neighborhood, responsiveness of transit service, the number of neighborhood places of significance, size and proximity of parkland, and sidewalk characteristics) to be scored. It was noted that this addressed the traditionally less measurable aspects of the walking environment, however as it was created to rate whole neighborhoods, its usefulness in addressing intersections is limited (Bradshaw, 1998).

Intersection Service for Cyclists

Unlike pedestrians, who have their own space designated by crosswalks or sidewalks, bicycles share the road with cars, making them more vulnerable to collision. As with pedestrian traffic, the Federal Highway Administration’s Guide to Signalized Intersection outlines the conditions for bicycles at intersections, providing a context for rating the quality of the experience.

Intersection Characteristics that Affect Bicycles:

1. Space for cyclists

First, it is important to consider the amount of space that bicycles need on the road. The FHWA sets the minimum width for bike lanes (or space for bikes) at 4 feet (see appendix). For facilities with high motor vehicle volumes or speeds, such as most high-volume signalized intersection, the FHWA considers 5 feet or more of operating space for cyclists to be desirable (FHWA 1994). Additionally, this space should be completely clear of obstacles and debris like drain inlets and utility covers, especially between 32 to 40 inches of the curb where cyclists tend to bike (FHWA 1994).

2. Potential Motorist-Cyclist Conflict:

Given the low visibility of cyclists and their tendency to share space with motor vehicles, it is no surprise that the risk for collision while cycling is approximately three times higher than for driving a motor vehicle over the same distance (Ho and Hemsing, 1997). In the same study, cycling collisions that occurred at signalized intersections accounted for 17 percent of all collisions. In just over half of these crashes, the cyclist was struck while crossing the intersection within the pedestrian crosswalk.

The FHWA lists four common situations where bicycle-vehicle crashes occur[2], and of these four, three occur at intersections (FHWA 1995):

1. Left-turning vehicles hitting cyclists head-on
2. Cyclists turning left in front of oncoming traffic
3. Cyclists moving through an intersection from a stop sign or flashing red signal

Other opportunities for vehicle-bicycle conflict at intersections occur as well. A diagram from the FHWA's Signalized Intersection Guide shows that cyclists going straight through an intersection encounter the same conflicts as motor vehicles, as well as additional potential conflicts from motor vehicles turning right from the same direction (for diagram in appendix).

Measuring Level of Service for Cyclists:

The most official method of measuring quality of service for bicycles is through the LOS model developed in Transportation Research Record 1578. It was developed with a background of over 60,000 miles of evaluated urban, suburban, and rural roads and streets across North America, and, as a result, has the highest correlation coefficient (R 2 = 0.77) of any form of the Bicycle LOS Model (Landis, 1997). Although created for roadways, the model's use of factors such as roadway width, bike lane widths and striping combinations, traffic volume, pavement surface conditions, motor vehicles' speed and type, and on-street parking is equally applicable to intersections.

The value for LOS is calculated using the factors: volume of traffic, number of lanes, speed limit, percentage of heavy vehicles, pavement quality, and width of traffic lane. These factors are calculated (for formula, see appendix) and summed, with the resulting value corresponding to letter grades that range from A (a score of less than 1.5) through F (a score of over 5.5) (Landis, 1997).

Alternative model of level of service for cyclists:

An alternative calculation of Level of Service that focuses more on intersections was submitted to the Transportation Research Board in 2002 by the Florida DOT. It used an actual study involving 60 cyclists (of different ages, genders, geographic origins) interacting with a variety of intersections, yielding a model of Bicycle Level of Service depending upon the perceived hazard of sharing the roadway environment, the width of the outside through lane and bike lane, crossing distance on the street, volume of traffic, and the number of traffic lanes (FDoT 2002) (see appendix for formula).

[2] The fourth type of collision occurs when motorists exit a driveway or alley

Applications:

How does this data relate to the Snelling/University site?

Although countless applications of the traffic literature reviewed can be made with the intersection of Snelling and University, this paper outlines two examples - the relationship between traffic and business and the trend of Transit-Oriented Development – that significantly affect the intersection of Snelling/University.

Anecdotal Data from local businesses:

An informal survey of several businesses located near the Snelling/University intersection on their view of traffic yielded results unsurprisingly consistent with previous literature written on the effects of congestion on business[3].

For example, the majority of retail shops addressed were happy with the level of traffic or were in favor of increased traffic. The manager of Love Doctor on University Avenue explained his preference for more cars with the equation "more people = more money". This sentiment was echoed by other retailers who ranged from the manager of Midway Books ("more cars, more business"), to the manager of the CVS chain on the corner ("More access means more convenience which would drive business").

Businesses such as the Verizon outlet on the corner of Spruce Tree Lane, Furniture Barn, Big Top Liquors and Roni's Beauty Supply all independently cited visibility as of extreme importance to their establishments and an asset of the area. The manager of Furniture Barn stated not only that most of their business is derived from potential customers seeing their sign while driving by or at the intersection, but related visibility to high rates of congestion, saying "the slower the traffic is going, the better for us".

These sentiments run parallel to the 1995 NCHRP study that determined urban retailers may locate themselves in congested areas for the increased visibility and access of their stores (TRB, 1995). Similarly, the study's claim that retailers avoid costs of congestion (such as commute costs and shipping costs) through their hours and methods of business operations may account for the positive traffic responses received at the Snelling/University cite. The responses to the informal survey do not, however, represent the majority of businesses in the surrounding area; however, like the over-all business make-up along Snelling and University, the majority were small retail establishments.

Transit-Oriented Development on the University Corridor

The University Avenue corridor has been the subject of developments for years, and other major intersections along it have faced similar issues as Snelling/University. For example, the city created a Transit-Oriented Development study for the Lexington/University intersection and the Snelling/University intersection in 2002; two years later, they created one for the major intersection of Dale/University.

Case Study: Lexington/University Intersection

[3] Business managers of 12 establishments within a block radius of Snelling/University were asked about their feelings on congestion and proximity to the intersection August 6 through 8, 2007.

The TOD study at Lexington/University resulted in a TOD framework plan that was adopted as an amendment to the City's Comprehensive Plan in 2004 (UU, 2003). The plan supported mixed-use, transit-oriented development, however despite laws that zoning codes and Comprehensive Plans must be consistent, the zoning for the land was never changed.

In part due to the lack of new zoning codes, the Lexington/University intersection was developed and approved in a piecemeal fashion, instead of one comprehensive plan, a decision appealed by the community coalition University United (UU) and the Lexington Hamline Community Council. According to UU and Lexington Hamline Community Council member Jessica Treat, the city's plan for development was contested because of its lack of integration with corridor plans, lack of TOD levels of high density and housing, and overall lack of cohesion. The city's plans to split the lot and develop them separately were maintained.

Case Study: Dale/University Intersection

The Dale/University TOD study created in 2004 was recommended by the Planning Commission on January 9, 2004 and adopted by the City Council on February 25, 2004 as part of their Comprehensive City Plan. The goals of the plan were to decrease the visibility of parking lots, increase mixed-use development, and diversify the types and prices of housing (SPPC 2004).

Unlike the development of the Lexington/University intersection, the Dale/University site was rezoned by the city. Because of rezoning, the development was restricted to mixed-use and transit-oriented guidelines laid out in the TOD plan.

Conclusion:

As intersections and traffic serve a variety of needs and have a variety of effects, there are countless methods to measure their service. The Highway Capacity Manual's criteria for Level of Service, the criteria used by the city of St Paul to rate the Snelling/University intersection, is only one of many. This measurement is beneficial because of its legitimacy with government and academic authorities of transportation, its quantitative measures that eliminate the error possible with subjective qualitative values, and its ease of calculation. However, criticism exists over its method of creation and calculation. The most common criticisms of LOS include:

1. LOS was created by and based on standards of traffic engineers, not "average motorists", nor, for that matter, pedestrians or cyclists.
2. The levels of tolerated congestion have not been updated in the past 15 years to adjust for changes in attitudes towards transportation and congestion.
3. LOS is calculated based on only one variable – motor vehicle control delay – whereas alternative measures of intersection service deem equally or more significant variables such as: pedestrian safety, bicycle safety, aesthetics, etc.

The use of LOS shows a commitment to national and academic standards of measurement, as well as a definition of congestion as the delay suffered by individual motorists. This definition of congestion prioritizes the cost of motorist delay over other costs that may be more pertinent to other groups (ie the benefits of traffic for nearby businesses).

Based on the other types of transportation measurements reviewed in this paper, recommendations for an augmented approach to intersection quality include:

- **Addressing other subjects (in addition to motorists) that experience the costs and benefits of congestion**. Other groups with a vested interest in intersection quality include local business, residents, and non-motorists who pass through the intersection. (see Pedestrian and Cyclist Levels of Service)
- **Addressing other costs of congestion, aside from motorist delay.** Other negative effects of congestion include increased noise, air pollution and danger for pedestrians and cyclists.
- **Acknowledging the benefits of congestion.** If addressed, benefits that come from congestion – increased access to goods and services and economic growth, among others – don't necessarily have to be eliminated with less-desirable effects of traffic (See Costs and Benefits of Congestion and Effects of Congestion on Business)

These concerns can be addressed in the measurement of intersection quality by using other or a variety of intersection measurements.

In general, the choice of an intersection quality measurement will always be a political one: it is impossible to measure all effects of congestion on all parties affected by intersections. However, the choice can be as informed and conscientious as possible.

Appendix

Congestion Burden Index: the TTI's 1999 travel rate index multiplied by the percentage of the workforce driving to work from the 1990 US Census

Transportation Choice Ratio: the miles of public transportation service per household offered over the period of one hour divided by the number of lane miles of principle arterials per household in that area

Level of Service for Signalized Intersections (HCM 2000):

Control delay = initial deceleration delay + queue move-up time + stopped delay + final acceleration delay

Control Delay (in seconds)	< 10	10 – 20	20 – 35	35 – 55	55 - 80	> 80
Level of Service	A	B	C	D	E	F

Pedestrian Hazard Index (Robertson, 1988):

Pedestrian Hazard Index = NA + RA + PS + NC + C

all variables measured with values between 0 – 100:

0 = No Hazard
33 = Low Hazard
67 = High Hazard
100 = Extreme Hazard

RA = rate of pedestrian accidents = accident frequency / (pedestrian volume x intersection length)

PS = proportion of special pedestrians crossing

NC = non-compliance with the signal

C = number of pedestrian/vehicle conflicts

FDoT Pedestrian LOS (FDoT 1999):

Ped LOS = a (RTOR + PL) + b (PTV * PTS) + c ln(PD) + d (LC^.514) + E

RTOR = right turn on red vehicles
PL = number of motorists making a permitted left turn in a 15 minute time period
PTV = traffic in the outside through lane of the street being crossed in 15 minutes
PTS = the midblock 85th percentile speed of traffic on the street being crossed
LC = number of lanes crossed by the pedestrian
PD = average number of seconds of pedestrian delay
E = constant

Space for bicycles (FHWA Signalized Intersection Guide)

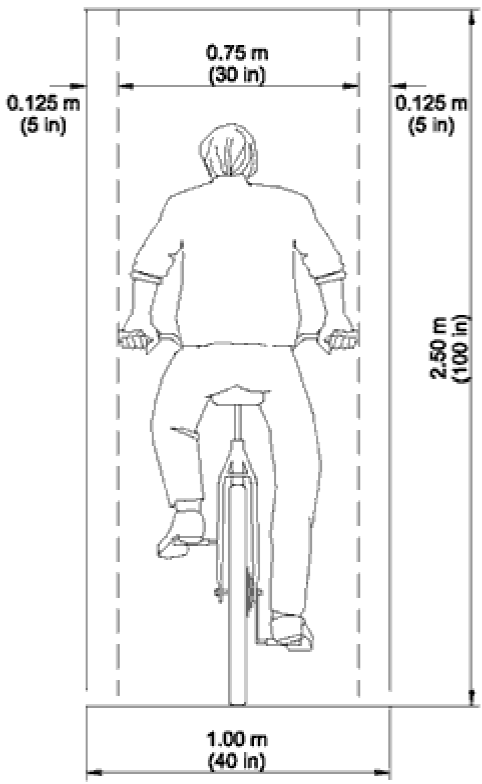
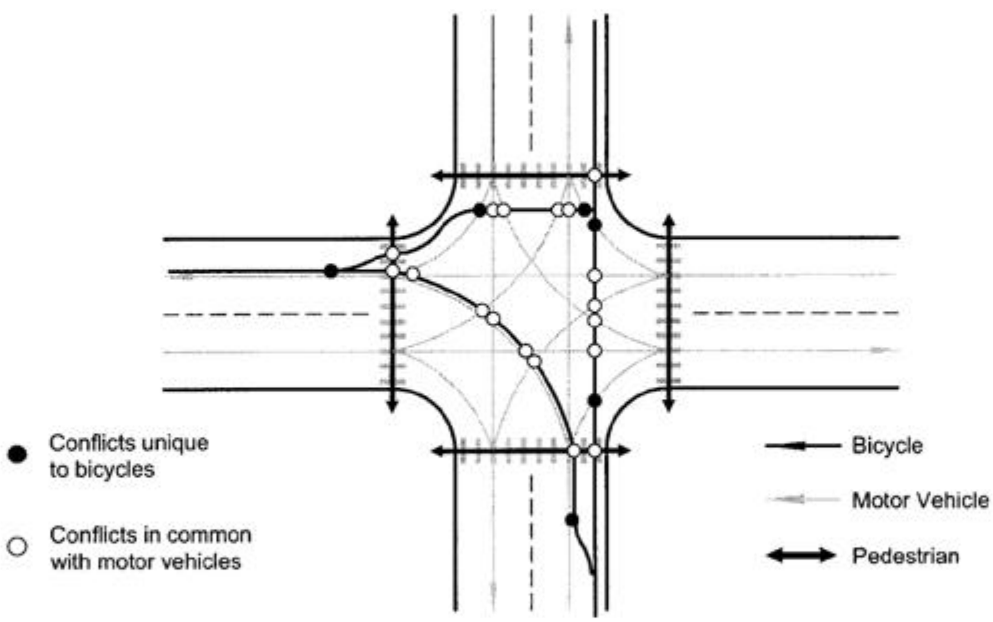


Diagram of potential cyclist collisions at intersections (FHWA Signalized Intersection Guide):



Bicycle Level of Service (Landis, 1997):

Bicycle LOS = a1ln (Vol/Ln) + a2SP(1+10.38HV) 2 + a 3(1/PR) 2 + a 4 (W) 2 + C

Vol = Volume of directional traffic in 15 minute time period

Ln = Total number of directional through lanes

SP = Effective speed limit

HV = percentage of heavy vehicles

PR = FHWA’s five point pavement surface condition rating

W = Average effective width of outside through lane

and a1: 0.507 a2: 0.199 a3: 7.066 a4: - 0.005 C: 0.760

FDoT Bicycle Level of Service (FDoT 2002):

BLOS = a1W + a2CD + a3(Vol/L) + C

BLOS = perceived hazard of shared-roadway environment through the intersection

W = total width of outside through lane and bike lane (if present)

CD = crossing distance, the width of the side street (including auxiliary lanes and median)

Vol = volume of directional traffic during a 15-minute time period

L = total number of through lanes on the approach to the intersection

C, a1, a2, and a3 = constants

Glossary

Autocentrism: the tendency to base attitudes and approaches to traffic (or transportation issues) around automobiles and motorists, as opposed to alternative methods of transportation

Capacity: the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions

Capacity Improvement: expanding the amount of users a traffic facility can accommodate, such as adding more lanes to a highway or creating new roads

Delay: the amount of time spent waiting at an intersection

High-Density Development: purposefully creating many jobs and residences in one area, in order to cut down on the amount of transportation facilities necessary

Induced Demand: the increased demand that comes for roadways with capacity improvement

Intermodal: accommodating of more than one type of transportation (ie busses and bicycles and autobomobiles)

Mitigate: to lessen in intensity

Mobility: the ability to move quickly and freely

Peak-period: the time periods during the day with the greatest volume of traffic, generally the two to three hour periods thought of as “rush hour”

Transit-Oriented Development (TOD): a pattern of land development designed to support public transit services

Transportation Demand Management (TDM): a strategy of instituting largely financial incentives and disincentives to encourage motorists to alternate routes, times and modes, or to defer trips entirely in order to reduce the demand for traffic facilities

Travel Rate Index: a measure of the extra time a trip takes because of peak hour congestion

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